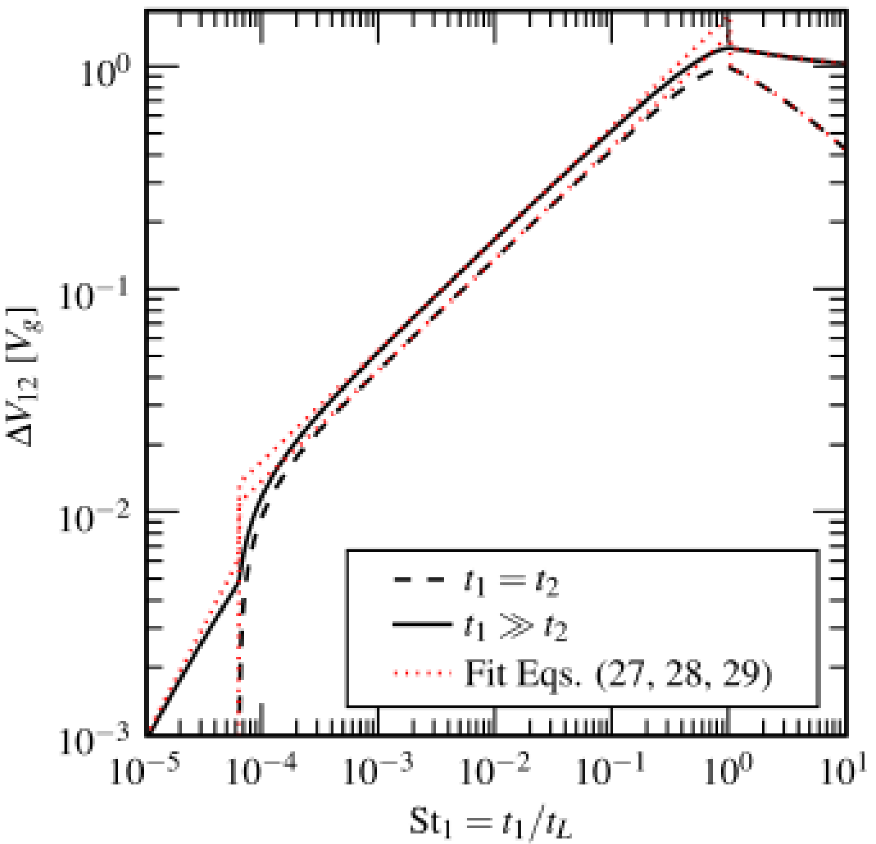
Collision Speeds of Equal-Sized Particles

Paolo Padoan (University of California, San Diego)
Collaborators: John Scalo (UTA), Alexei Kritsuk (UCSD), Mike Norman (UCSD), Lubin Pan (UCSD)

Standard result for particle collision velocities:
Eddy-interaction model by Volk et al. (1980); with further improvements in Mizuno et al. (1988), Markiewicz et al. (1991), Cuzzi et al. (1993), Cuzzi and Hogan (2003), Ormel and Cuzzi (2007).



Never been tested experimentally or numerically, or even against other models (several in the physics literature). (Some aspects tested numerically in Carballido et al. 2008)

We are interested in testing the eddy-interaction model and in comparing it with other models.

For now only particles of equal size.

Simulation:

512^3 computational zones
$2x512^3$ particles, with 16 different Stokes numbers.
Re_lambda ~ 200, Re ~ 2800 (largest study in the physics literature Re_lambda ~ 80).

We resolve the inertial range in the gas, but it is not extended enough to allow a range of Stokes numbers satisfying the strong inequality:

$$1 \ll St_{\mathrm{K}} \ll Re^{1/2}$$

So we are testing the dissipation range primarily (hence not very large Stokes number), but this range is very interesting because:

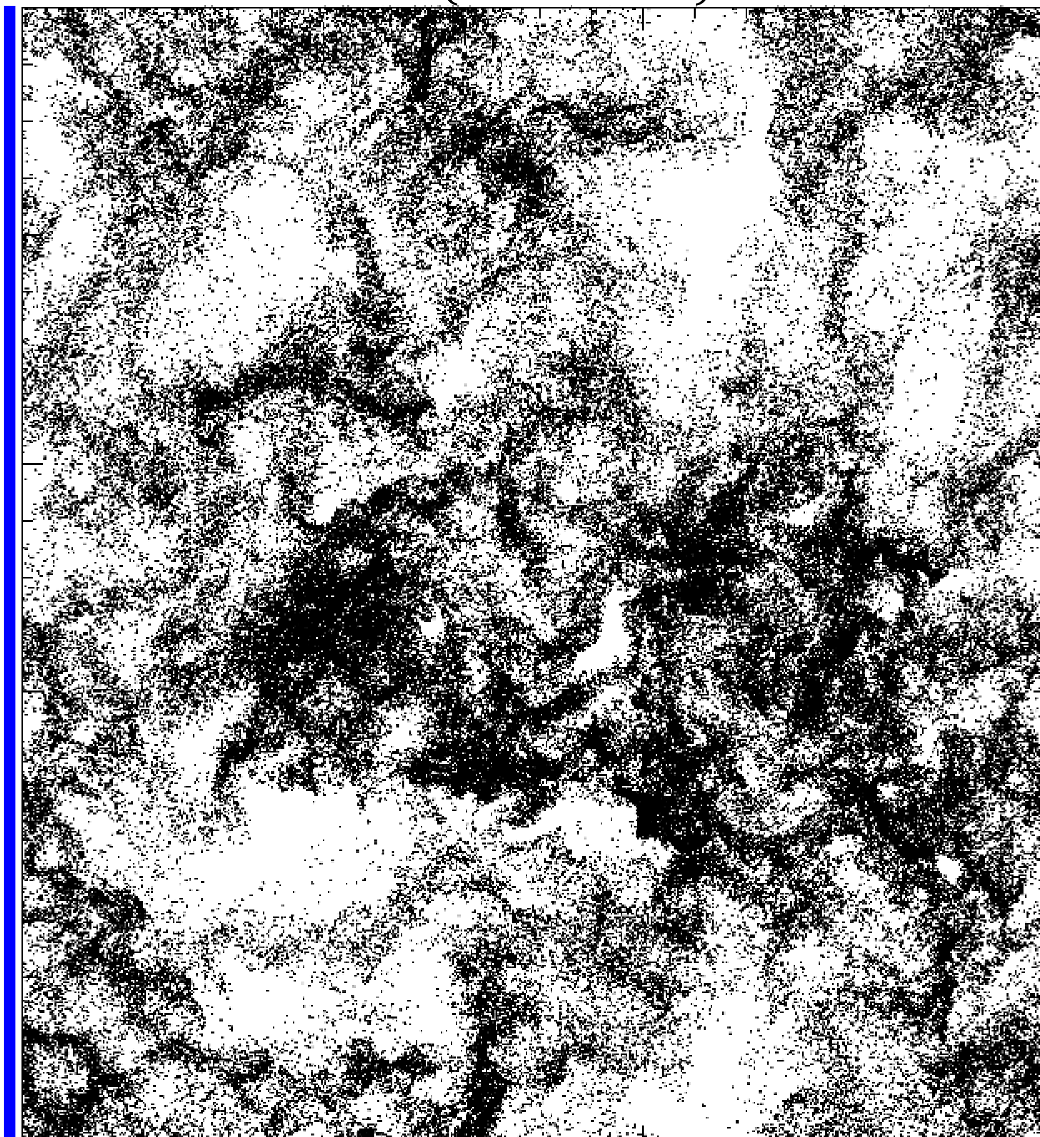
- It produces turbulent clustering of particles
- It is relevant to the early evolution of grains in disks up to mm size (even much larger with fractal growth or for large gas density)
- It is the same regime found in current disk MRI simulations (rather low Re) used to study the dynamics of embedded particles.

Numerical Simulations of Compressible Turbulence

$N_{\text{mesh}} = 512^3$; $N_{\text{particles}} = 2\,x\,512^3$ (17 Stokes numbers), $M_S = 1$

S=1.2 (0 < z < 10)

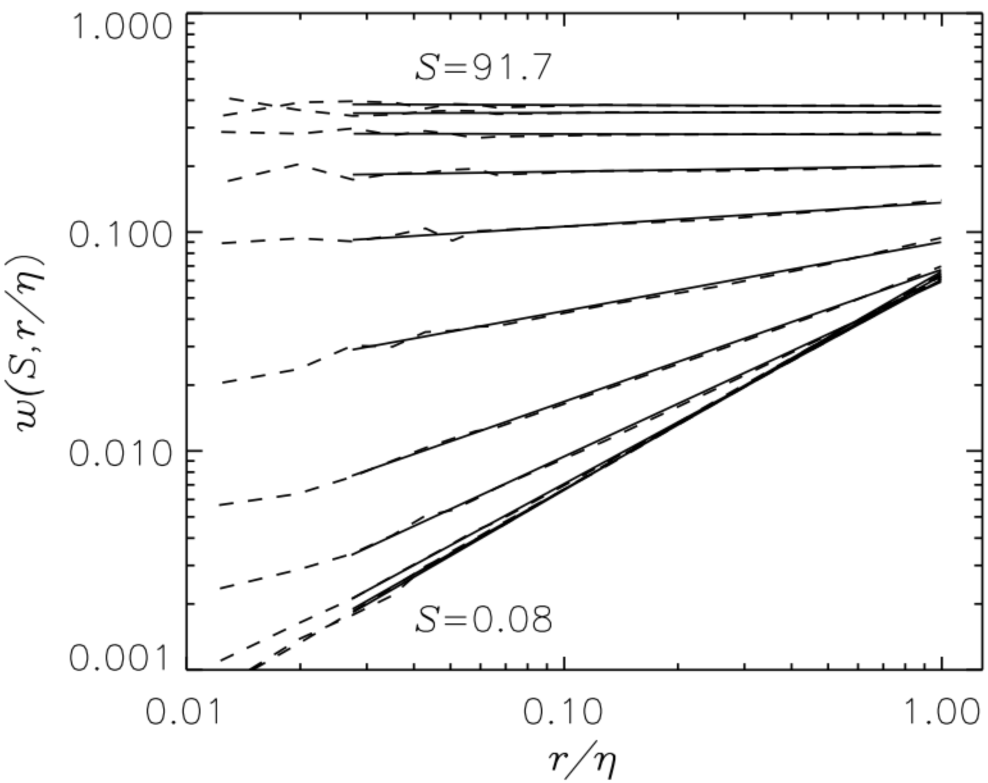
S=5 (0 < z < 10)

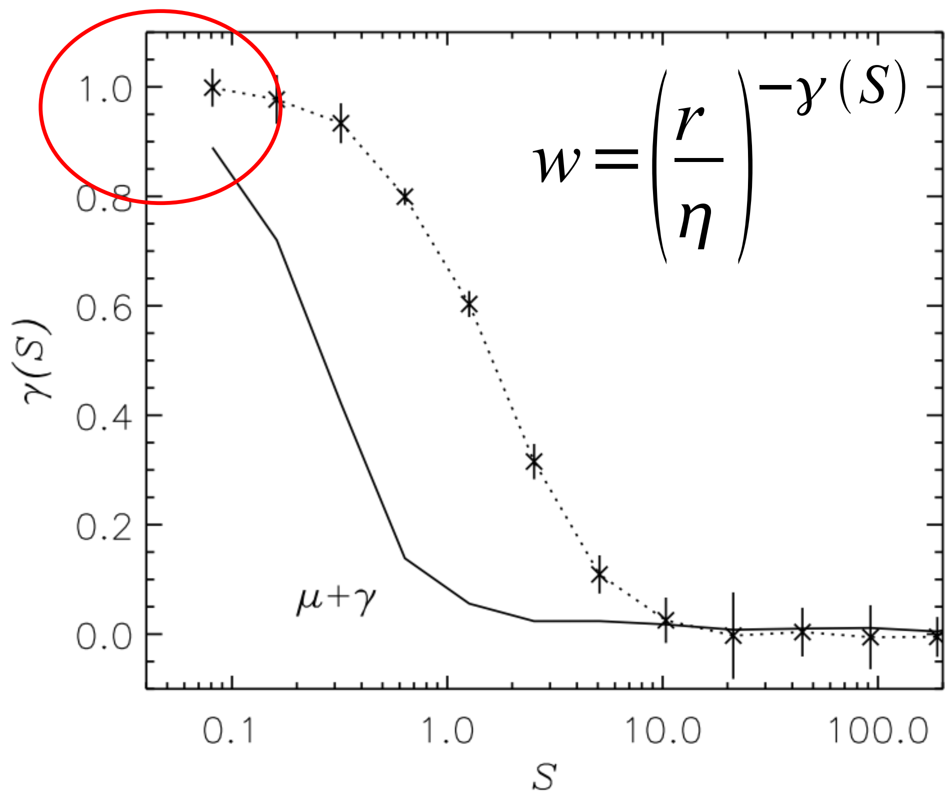


We measure the relative velocity of particles as a function of separation, for separation below the Kolmogorov scale.

1) The velocity depends on separation --> Collision speeds (at contact) can be very low

2) The velocity is clearly not zero for St_K<1



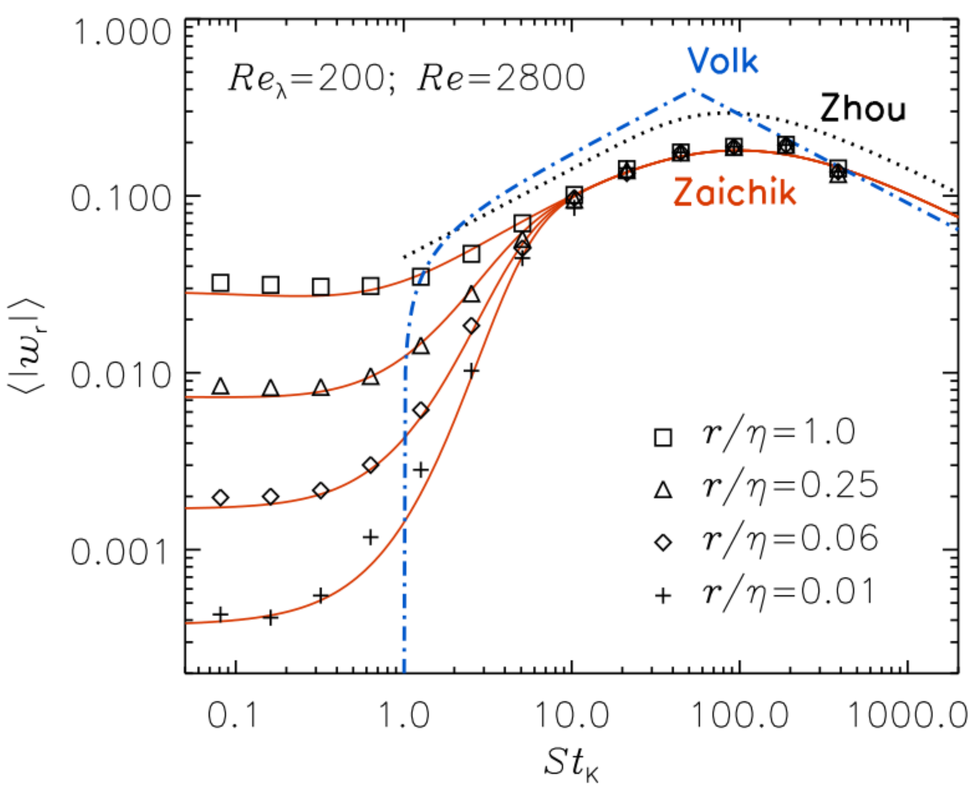


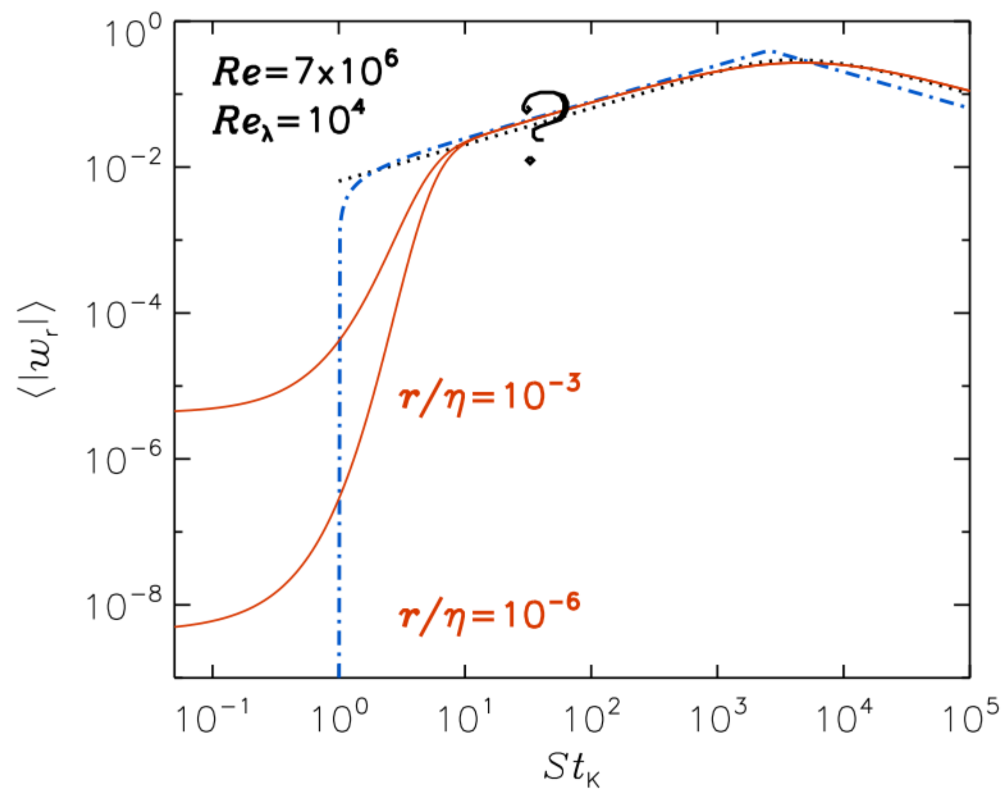
The non-zero relative velocity of equal size particles of St_K < 1 was expected, it is given by the well known Saffman-Turner limit for particles with St_K --> 0 (Saffman and Turner 1956):

The velocity field is linear below the Kolmogorov dissipation scale, so the velocity gradient is scale-independent, but not zero as assumed in the eddy interaction model (Volk ....).

3) Particle relative velocity is lower than the St^1/2 dependence of the inertial range already below St_K~10 (could it be 20, or 100 if Re~10^{10} ?).

4) Good agreement with a model based on a kinetic equation for the probability density function of the relative velocity of 2 particles (Zaichik et al. 2003).





However, the comparison is still primarily at relatively low Reynolds number.